FERMILAB-Proposal-0650

Request for a Continuation of E-567

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During the fall running period of 1979 our group was able to conclude our first and only major data taking run for E-567. Using the spectrometer shown in Figure 1, we were able to accumulate data for the equivalent of 600 hrs. of stable running (400 GeV accelerator operation with one second spill and > 90% beam duty factor). During this time, we recorded approximately 8×10^7 events on 400 magnetic tapes. The integrated flux of pions on our 1.8 g/cm^2 target of beryllium was $\sim 1 \times 10^{13}$ at a beam momentum of 200 GeV/c. Folding in the efficiency for D^* detection averaged over all x and P_t of (3.4×10^{-4}) and the analysis and trigger efficiencies of (.15) results in a sensitivity of .57 events/nb for $D^* \to D^\circ\pi$. In the Monte Carlo for the accept-

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow K\pi$

ance of the apparatus we have used an x dependence of $(1-x)^3$ and a P_t dependence of $e^{-1.10P_t^2}$. Using the known branching ratios from SPEAR, we have a sensitivity for total inclusive D^* production of 8.5 events/ μb.*

In order to be assured that the spectrometer and the associated analysis programs were properly functioning, we recorded simultaneously with our D^* candidates the following calibration reactions: (a) $\pi^- N \to J/\psi + X$ and

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow \mu^+\mu^-$

(b) $\pi^- N \to \Lambda^\circ\pi + X$. The J/ψ data performed two important functions. First, the

$\quad\quad\quad \hookrightarrow p\pi^-$

J/ψ provided a convenient mass calibration for the "fast" arms.

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*We express our results in the form of a total cross section limit with the previously described x and P_t dependences, to enable an easier comparison with other charmed particle searches. In order to convert these cross sections to the equivalent $\frac{d\sigma}{dx}\big|_{x\cong 0}$ or $\frac{d\sigma}{dy}\big|_{y\cong 0}$ limits multiply by the factors 1.52 and 0.29 respectively.

The data are shown in Figure 2 and the mass resolution observed is consistent with that expected based on chamber resolution and multiple scattering effects. Second, these data also provided us with an independent sensitivity check, since $B \frac{d\sigma}{dx}$ has been measured for J/ψ production by pions at 225 GeV/c.[1] Using the value of $B \frac{d\sigma}{dx} = 20$ nb and a geometrical acceptance of 1.4×10^{-3} integrated over x and P_t, we arrive at a consistent flux measurement of $10^{13}\pi^-$ on target. The $\Lambda°$ data provided a very important check of the performance of both "fast" and "slow" arms during the experiment. The $\Lambda°$ decay topology required the proton enter either of the "fast" arms and the pion be detected in the "slow" pion spectrometer. This geometrical configuration conveniently spans momentum regions similar to those populated by D^* decays in 2 of the 3 arms. The results of these data are displayed in the $p\pi^-$ and $\bar{p}\pi^+$ mass distributions in Figure 3. The ability to see the $\Lambda°$ decays, whose kinematics are similar to D^* decays, provided an important base for merging the data from the two (fast and slow) spectrometers.

The complete analysis of the D^* data has recently been concluded and the final results are displayed in Figure 4. In this histogram we display the two body $K\pi$ invariant mass for both the D^{*+} and D^{*-} candidates in the data sample which have a Q value consistent with the measured Q value of 5.7±.5 MeV, where, $Q = M_{K\pi\pi} - M_{K\pi} - M_\pi$. The Q value cut used weights the difference between the measured and known values of Q by the measurement error δQ on an event by event basis. We have defined a variable $R \equiv \left| \frac{Q_{measure} - 5.7}{\delta Q_{measure}} \right|$ and calculate its value for each event, those events for which $R \leq 1.5$ appear as entries in the $K\pi$ mass distributions of Figure 4. The values of δQ for the data are typically .6 MeV. However, there is some dependence on the kinematic variables in a given decay and these have been taken into account in our calculation of R for each event.

Also shown on this histogram of the data is the result of a fit to the final distribution, by a combination of polynominal background of order 3 and a Gaussian peak of arbitrary mass but with a fixed width of 15 MeV. The best fit to this function is shown as the solid curve on the histogram. The program finds a peak of 66±25 event in the mass region around 1.865 GeV/c^2 for $K^{\pm}\pi^{\mp}$ states. Using the previously calculated sensitivity to convert to a cross section we find a $\sigma(D^{*\pm}_{AVE}) = \frac{\sigma(D^{*+} + D^{*-})}{2} = 3.8 \pm 1.5$ μb.

We now compare this result for D^* production with the two most recent results from particle searches at Fermilab energies. First, the Yale-FNAL streamer chamber group[2] recently published a cross section for production of short lived new particle states by 350 GeV/c protons of 20-50 μb. Second, the Caltech-FNAL-Rochester-Stanford[3] group observed an excess of prompt muons in 350 GeV/c proton interactions consistent with a total charmed particle production cross section of 35±15 μb.[4] To make a direct comparison of these three experiments one needs to make some assumption regarding the relative rates of production of the various members of the charmed particle family. Using the theoretical predictions of Rosner[5] as a best guess for these relative cross sections, we expect that about 45% of the charm cross section contains a D°, and of this we expect about 52% of the D°'s have come from D^* decays. This results in an estimate of D^* production from the beam dump experiment of 8±3 μb and from the streamer chamber data of 4.5-11.7 μb. Our result is in reasonably good agreement with these two experiments interpreting our 2.6σ enhancement as a D^* signal.

These two experiments cited for their recent results are vastly different from our own. While they both have very good acceptances, they are both unable to observe charm production directly through invariant mass enhancements as we are able to do with our detector. Because of these differences we consider our efforts to be entirely complementary to those of the other groups, and as such provides an important addition to our knowledge of the hadronic production of charmed particles.

Our group feels that it is extremely important to be able to successfully conclude this experiment, an effort which we consider to be at best only half done at this point. We have given careful thought as to how we might improve our initial measurement through another data taking run. After studying the situation we find there are several aspects of the detector which could be improved and they are as follows:

(1) Better slow pion trigger selection. This requires reducing the solid angle seen by our existing slow pion arm, since one of the pacing elements in increasing our sensitivity is the present trigger rate. By reducing the fiducial area, the acceptance for D^* events is unchanged while the area and hence the trigger rate in this hodoscope is reduced by 30%.

(2) We plan to improve the momentum selection trigger in the "fast" arms by making a very simple trigger processor to select $K\pi$ masses in the mass range above 1.7 GeV/c^2 thereby reducing our trigger rate by $\sim$ 50%.

(3) We plan to improve our two body invariant mass resolution by reducing the amount of multiple scattering in the "fast" arms through changing the filling of the upstream differential Čerenkov counter from Freon 114 to Isobutane. This provides us with a 30% improvement in mass resolution. The counter was designed

for operation with flammable gases so we do not envision any great problem in satisfying safety requirements.

(4) We plan to improve upon our present vertex resolution ($\sigma_{xy} \sim .1''$) by making two changes, (a) segment the target in the vertical dimension into 5 or 6 (.1") high pieces separated longitudinally by 3-4 inches and (b) to install a new set of drift planes as close as possible to the down stream end of the Henry Higgins analyzing magnet, thereby reducing the lever arm required to point to the target position. (See Figure 5) Carrying out both of these projects will improve the Q value resolution by 30% yielding $\delta Q \sim .4$ MeV.

(5) We plan on taking data at the highest available pion energy compatible with our flux requirements. This corresponds to a pion momentum of 275 GeV/c with approximately 1-2 x 10^{12} protons on target. This increase in energy could result in as much as a 15% increase in D^* production cross section should this cross section behave like that of the J/ψ over this energy interval. However, we have not included this factor in our cross section gains discussed previously.

Following these improvements in our detector we will be able to run with a factor of 3 increase in interaction rate and with an improved signal to background ratio by a factor of 1.5. This results in an increase in our sensitivity by a factor of at least 2. We have already measured the effect that such an increase in flux will have on reconstruction efficiency and find that this will not be a limitation.

Our request is then to receive an additional run of 500 hrs. to conclude E-567. This corresponds to roughly seven weeks of calendar time when "normal" machine performance is taken into account. With this additional data taking run we will be able to answer several as yet unanswered questions regarding charmed particle production by hadrons. These are:

(1) What is the cross section for particular inclusive charmed particle states? (Namely $D^{*\pm}$)

(2) Are these cross section levels consistent with prompt muon experiments?

And to a lesser extent we will also be able to provide information on:

(3) The characteristic P_t dependence of the D^* production.

(4) The energy dependence of the D^* cross section. Is it similar to J/ψ production?

Since our spectrometer system and analysis procedure has been developed over the last two years and has reached a stable state we are fairly confident that within a relatively short time following this extension the answers to these questions will be known.

Our collaboration is very eager to conclude this set of measurements and could therefore be ready to take data with the improved detector by November 1980. We are not insensitive to the scheduling difficulties facing experimenters in the High Intensity Area of the Proton Lab, however we feel that there would be adequate scheduling flexibility to allow our group the earliest possible access to beam in order to finish E-567.

References

(1) J. G. Branson, et al., Physical Review Letters, 38, p. 1331 (1977).
K. J. Anderson, et al., Physical Review Letters, 42, p. 944 (1979).

(2) J. Sandweiss, et al., Fermilab-PUB-80/16-EXP7550.490, "Observation of Hadronic Charm Production in a High Resolution Streamer Chamber Experiment", submitted to Phys. Rev. Letters, January 1980.

(3) J. L. Ritchie, et al., Physical Review Letters, 44, p. 230 (1980).

(4) The experimenters in ref. 3 have used a semileptonic branching ratio of 8% when generating their total charm cross section. We have corrected their cross section to account for a more reasonable level of total semileptonic branching ratio when averaging over all charmed states (5%), which is consistent with ref. 3 two muon data.

(5) J. L. Rosner, Proceedings of the Cosmic Ray and Particle Physics - 1978 (Bartol Conference) p. 297, T. K. Gaisser, editor.

Figure Captions

(1) Plan view of E-567 spectrometer system in its 75 mrad opening angle configuration.

(2) Invariant mass distributions for dimuon events part (a) containing opposite sign candidates and part (b) containing like sign candidates. The J/ψ signal is seen clearly in the opposite sign data with a $\sigma \sim 30$ MeV.

(3) Proton-pion invariant mass distributions for both $p\pi^-$(a) and $\bar{p}\pi^+$(b). These events were further selected to have a common vertex outside the nominal target region to enhance the Λ° signal. The mass resolution for the $p\pi^-$ sample is $\sigma \sim 2$ MeV.

(4) This is a histogram of the $K\pi$ invariant mass distribution for D^* candidates which have been selected by requiring the value $R = \left|\frac{5.7\ \text{MeV} - Q}{\delta Q}\right| <$ 1.5. A D^* signal would result in an enhancement at the $D°$ mass of 1865 MeV/c^2. Both signs of D^* candidates have been combined to make this distribution.

(5) This figure shows an elevation view of the "slow" pion spectrometer and illustrates the location of new chambers designed to improve vertex and Q-value resolution.

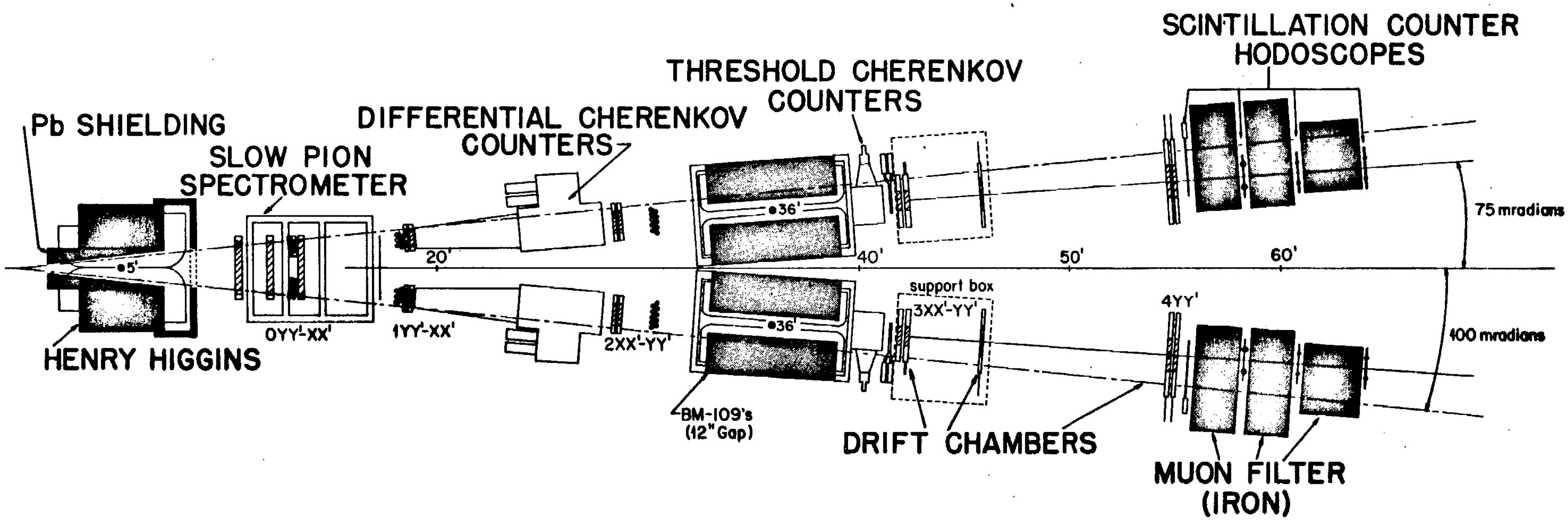
Pb SHIELDING
HENRY HIGGINS
5'
SLOW PION SPECTROMETER
0YY'-XX'
1YY'-XX'
20'
DIFFERENTIAL CHERENKOV COUNTERS
2XX'-YY'
THRESHOLD CHERENKOV COUNTERS
36'
36'
BM-109's (12" Gap)
40'
support box
3XX'-YY'
DRIFT CHAMBERS
50'
4YY'
60'
SCINTILLATION COUNTER HODOSCOPES
MUON FILTER (IRON)
75 mradians
400 mradians

FIGURE 1

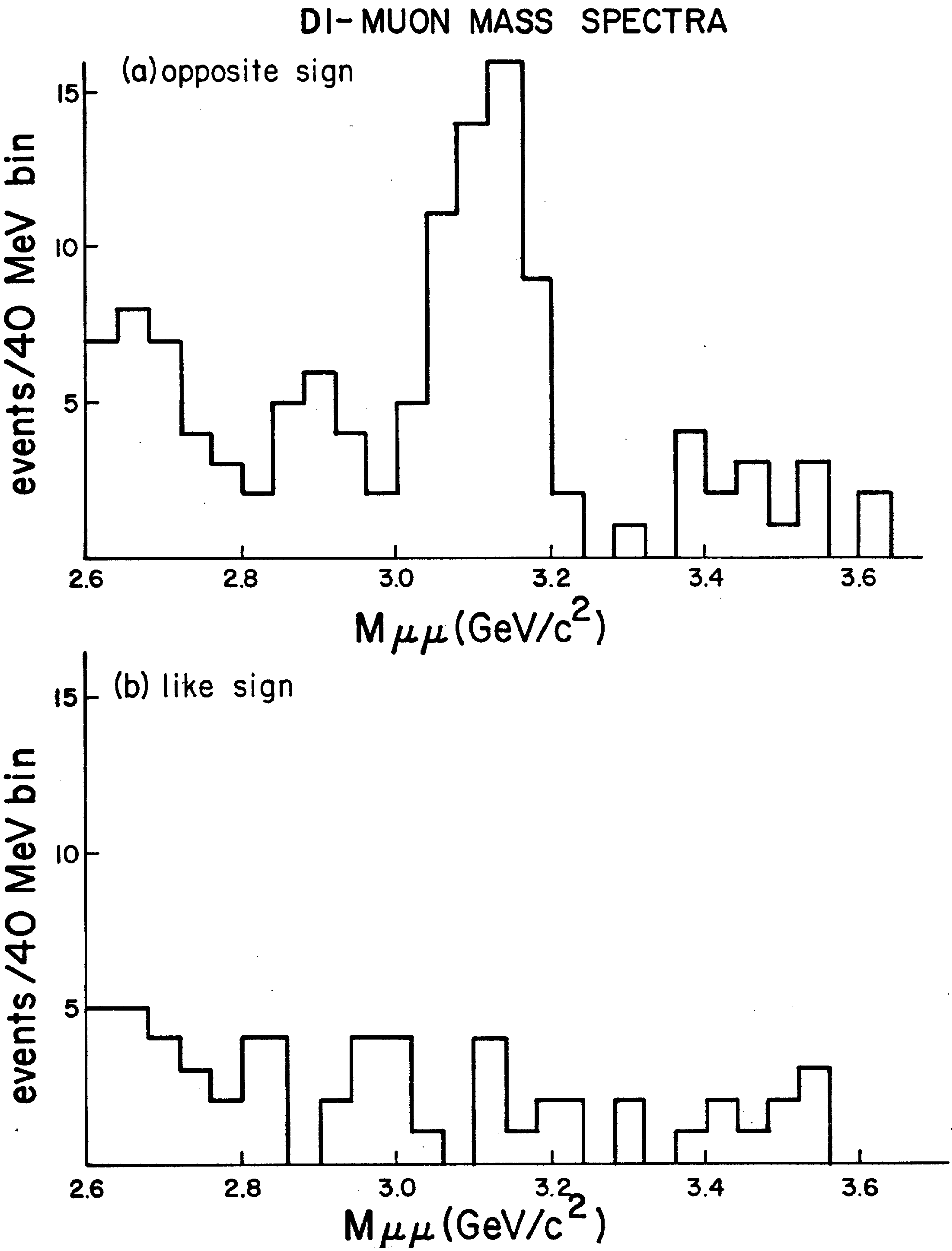
DI-MUON MASS SPECTRA
(a) opposite sign
events/40 MeV bin
15
10
5
2.6
2.8
3.0
3.2
3.4
3.6
$M_{\mu\mu}$ (GeV/c^2)
(b) like sign
events/40 MeV bin
15
10
5
2.6
2.8
3.0
3.2
3.4
3.6
$M_{\mu\mu}$ (GeV/c^2)

FIGURE 2

P π MASS SPECTRA

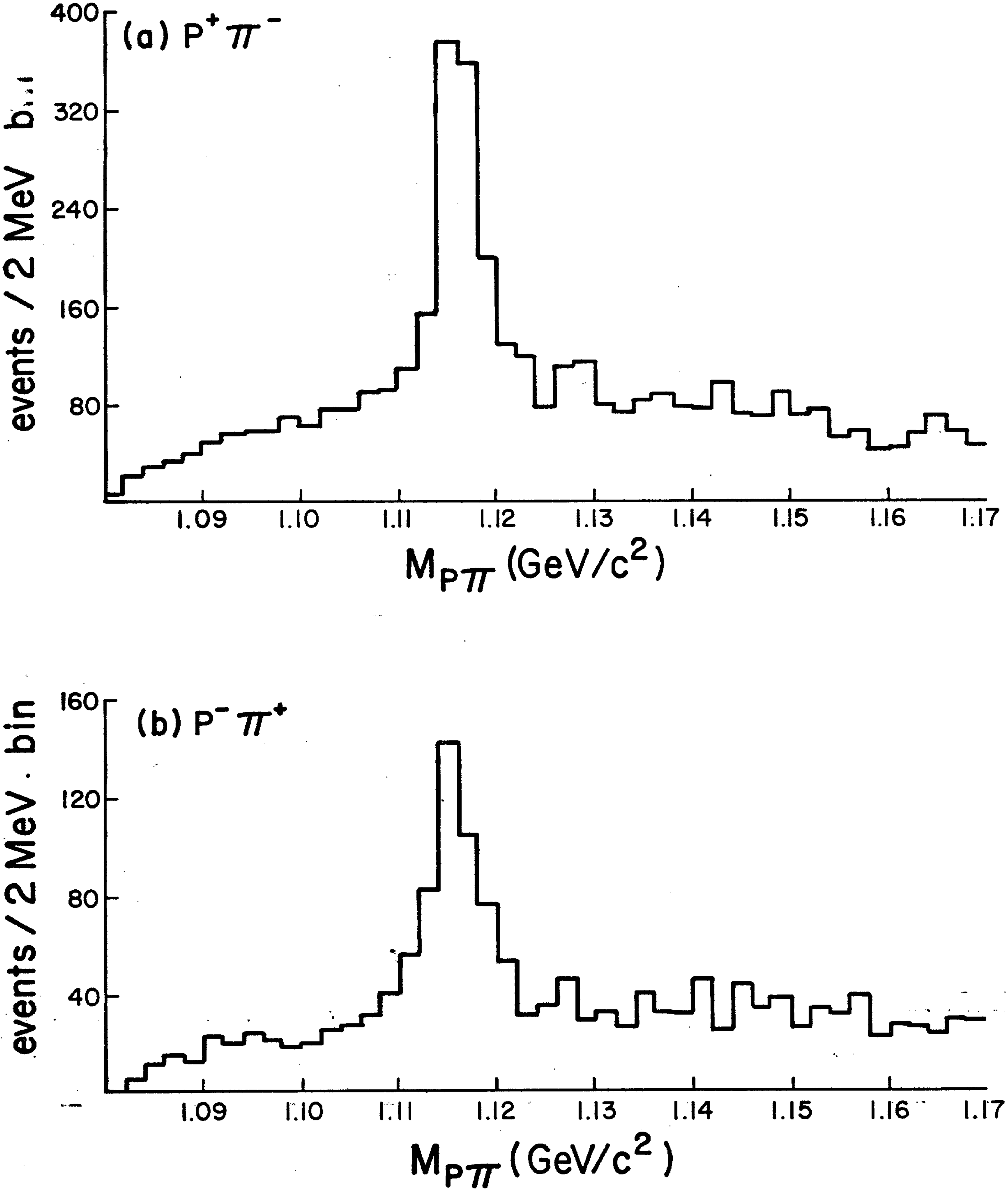

FIGURE 3

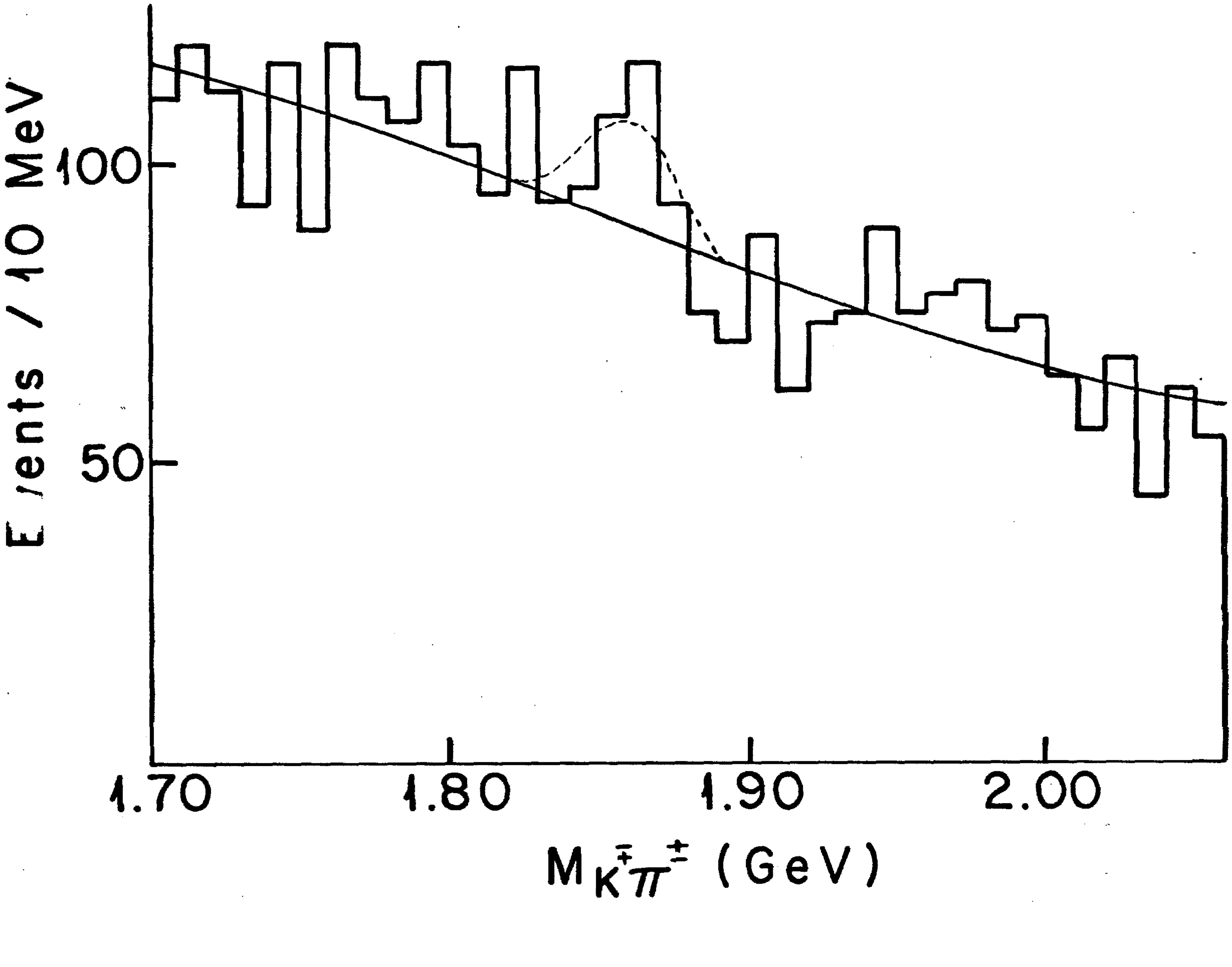

FIGURE 4

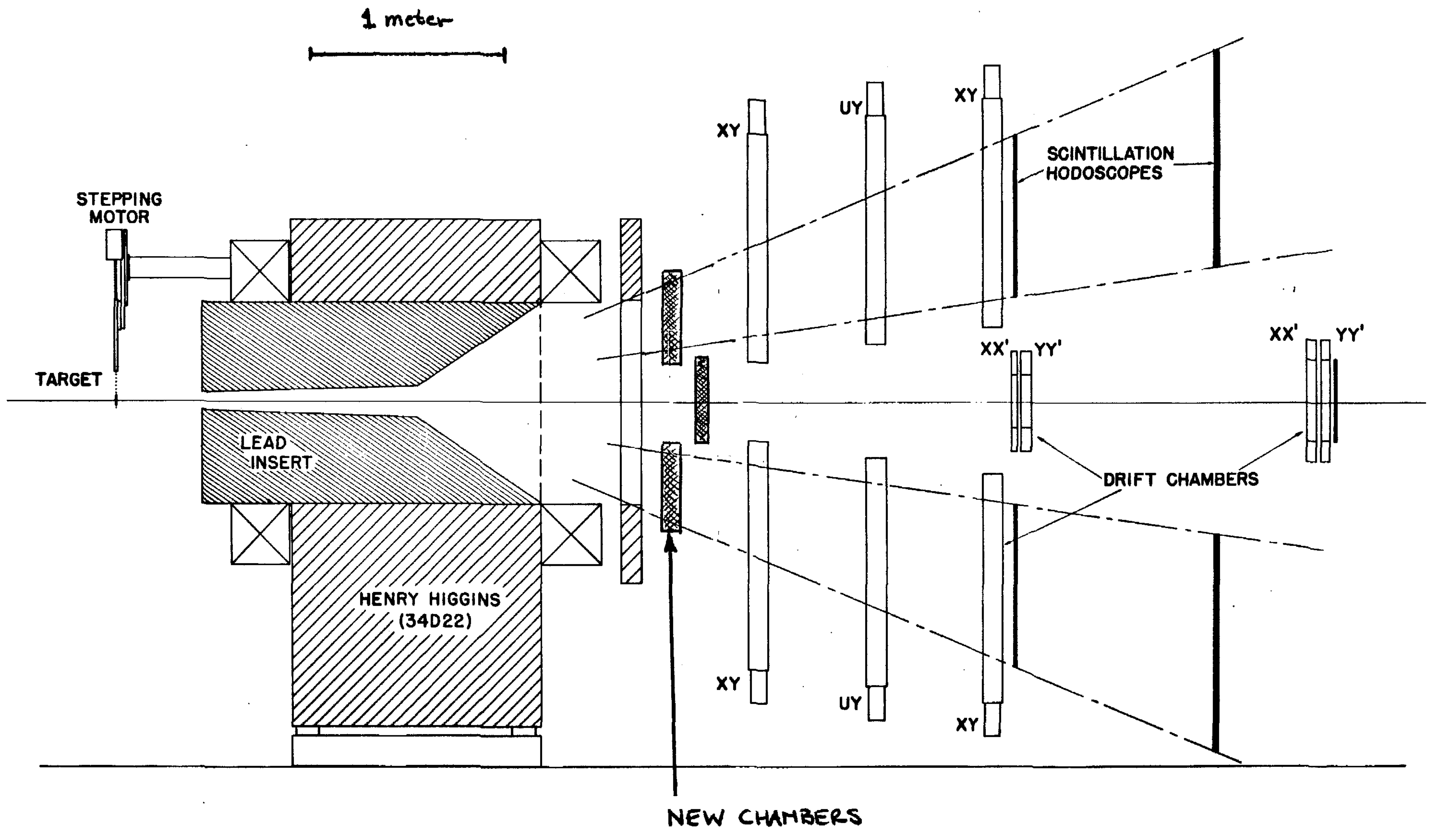
1 meter
STEPPING MOTOR
TARGET
LEAD INSERT
HENRY HIGGINS (34D22)
XY
UY
XY
XY
UY
XY
XX'
YY'
XX'
YY'
SCINTILLATION HODOSCOPES
DRIFT CHAMBERS
NEW CHAMBERS

FIGURE 5